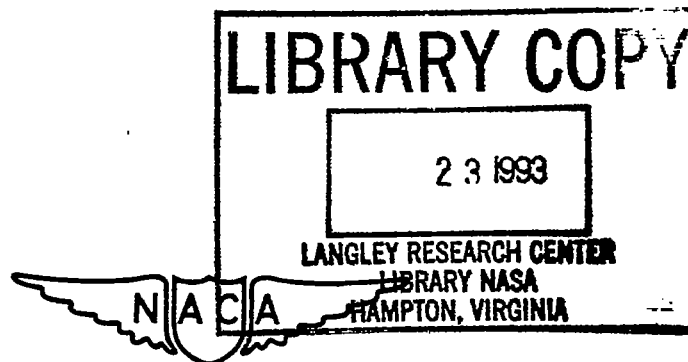# NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TECHNICAL NOTE

No. 1142

AN ANALYSIS OF THE AIRSPEEDS AND NORMAL ACCELERATIONS

OF DOUGLAS DC-3 AIRPLANES IN COMMERCIAL

TRANSPORT OPERATION

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Acceleration and airspeed data in the form of V-G
records from Douglas DC-3 airplanes operated over three
transcontinental routes in the United States have been
analyzed to determine the influences of route, forecasting
and dispatching practices, and operating speed on the
applied loads experienced during commercial transport
operation. The operational·life of airplanes was found
to be directly related to the operating speeds maintained
in regions of turbulence and to the forecasting facilities
and dispatching practices of the airline. During a given
period of operation, however, for transcontinental
operation in the United States, differences in route
roughness appear to be so compensated for by the fore-
casting and dispatching practices of the airlines that
route, as a significant parameter in airplane life, may
be neglected.

INTRODUCTION

The present report is the second prepared to give
the results of an analysis of V-G data from commercial
transport airplanes. The first report (reference 1)
dealt with data obtained from Boeing S-307 airplanes flying
in the Caribbean region. The present report is concerned
with an analysis of data obtained with Douglas DC-3
airplanes flying over three transcontinental routes in
the United States. The data have been analyzed in
accordance with the method of reference 2 to indicate
the influences on airplane life of route, dispatching
and forecasting practices, and operating speed.

SCOPE AND EVALUATION OF DATA

A total of 133 V-G records representing 54,210 hours of flight were available for the present analysis. These records were obtained with the NACA V-G recorder (reference 3) from DC-3 airplanes operated by three of the principal airlines of the United States during the period from 1937 to 1944. The records were supplied to the Langley Memorial Aeronautical Laboratory of the NACA by the airlines together with the dates of installation and removal, the number of flight hours per record, the routes flown during the time that the record was installed in the airplane, and occasional supplementary remarks regarding unusual atmospheric conditions or operating practices. Since no information was made available by the airlines on the operating weight and other characteristics of the airplanes pertinent to the present report, the design values as obtained from references 4 to 6 have been used. These values are presented in table I. The limit load factor of $3.14g$ was determined from the other airplane characteristics on the basis of the requirements set forth in reference 7. This value represents the acceleration that would result from an effective gust velocity of 30K foot per second encountered at maximum level-flight speed where K is the gust alleviation factor (reference 7). On the basis of the design gross weight of the DC-3 airplane, a value of K of 1.07 has been used in the present report.

A summary of the records supplied for analysis by each of the airlines (referred to hereinafter as airlines A, B, and C) is given in table II. Records were supplied by airline A from 1937 to 1944 and these records have been separated in table II according to prewar (before World War II) or war (during World War II) operation. Airlines B and C supplied records during only the prewar period. Inasmuch as the flight hours per record for each airline covered a fairly wide range, and since the method of analysis which has been employed requires that the flight time per record be held reasonably uniform, it was necessary to restrict the analysis to smaller groups of records for which the ranges of flight hours were not too great. The ranges of flight hours that were selected for each group of records are shown in table II together with a summary of the records that corresponded to those ranges. The choice of a suitable range of flight hours is somewhat arbitrary. The present choices, however,

conform to the statement given in reference 2 of the
ranges that are desirable in the application of the
present method of analysis.

No attempt has been made in the present analysis
to classify acceleration peaks as due to gusts, gust
maneuvers, or maneuvers. As in reference 1, the
assumption has been made that all large accelerations
in flight are due to gusts.

METHOD OF ANALYSIS AND RESULTS

The method of analysis of the data obtained with
the DC-3 airplanes is exactly the same as the method
used for the data obtained with the S-307 airplanes
(reference 1). Six values are read from each record:
the flight time, the maximum indicated airspeed V_{max},
the maximum positive and negative acceleration increments
Δn_{max}, and the indicated airspeeds V_0 at which these
maximum accelerations are experienced. The frequency
distributions of V_{max}, Δn_{max}, and V_0 for each of
the airlines are shown in tables III, IV, and V,
respectively. Because of the essential symmetry of
positive and negative acceleration increments, values
of Δn_{max} were combined without regard to sign.

With the aid of the computed mean value $\overline{V}_{max}$,
$\overline{\Delta n}_{max}$ or $\overline{V}_0$, and the computed values of the standard
deviation σ and the coefficient of skewness α, Pearson
Type III probability curves (reference 2) can be fitted
to each of the frequency distributions so that estimates
may be made of the probability of exceeding given values
of airspeed and acceleration. By means of these
probability curves and the values of the average record
time τ in table II, the average number of hours
required for each of airlines A, B, and C to exceed
different values of airspeed and acceleration has
been computed in the manner outlined in reference 1.
The results for airspeed and acceleration are shown in
figures 1 and 2, respectively. The curves of figures 1
and 2 are merely Pearson Type III probability curves
referred to a time scale. Values taken from figures 1
and 2 at the placard speed (nine-tenths of the maximum
gliding speed) of 257 miles per hour and at the

limit-load-factor increment of 2.14g of the DC-3 airplane
are summarized in figures 3 and 4.

By the procedure in reference 2, "flight envelopes"
have been constructed from the data for each of the
airlines. These envelopes predict that, in a given
number of flight hours, an average of one airspeed will
exceed the envelope, and an average of one positive and
one negative acceleration increment will exceed the
envelope with equal probability of being experienced
at any airspeed. For comparison with other data, the
flight envelopes corresponding to 10,000, 20,000, and
50,000 hours of flight by airline A during the prewar
and war periods and by airlines B and C during the
prewar period, are shown in figures 5, 6, 7, and 8,
respectively. The composite V-G envelopes representing
all the data supplied by each of the airlines are also
shown in figures 5 to 8. For purposes of comparison
the 5000-hour flight envelope has been included in
figure 8, inasmuch as only 4485 hours of records were
supplied by airline C. On several of the individual
V-G records the flight-acceleration peaks at low speeds
(100 to 120 miles per hour) were expunged by traces on
the records caused by landing shocks. The landing shocks
so exhibited on these records were not included in the
composite V-G envelopes of figures 5 to 8.

The flight envelopes have been converted, by means
of the sharp-edged-gust formula (reference 3), to gust-
velocity envelopes which predict that in a stated number
of flight hours, an average of one up gust and one down
gust will exceed the envelope with equal probability of
being encountered at any airspeed. The 50,000-hour
effective-gust-velocity envelopes corresponding to
the 50,000-hour flight envelopes of figures 5 to 8
are presented in figure 9.

PRECISION

The precision of the NACA V-G recorder and the
limitations of the method of analysis employed have
been discussed in reference 1. The inherent errors in
the V-G recorder should not exceed $\pm 0.2g$ for acceleration
and 3 percent of the full-scale value for airspeed.

The use of the design gross weight in the
calculation of effective gust velocities undoubtedly
results in conservative gust velocities since, so
far as is known, the DC-3 airplanes were not operated
at weights greater than their gross weights. Scheduled
operating times that were supplied by the airlines have
been used as the basis of a rough calculation of the
average gross weight of the airplane in flight and,
on the average, the effective gust velocity appears to
be conservative by about 5 percent.

DISCUSSION

Application of the methods of reference 2 to the
data obtained with the DC-3 airplanes has indicated
certain trends with regard to the influences of route,
forecasting and dispatching practices, and operating
speed on the life expectancy of commercial transport
airplanes.

For the analysis it is necessary to determine
what constitutes a significant difference between two
probabilities. The criterion adopted in reference 1 is
employed herein; namely, if one probability is greater
than the other by a ratio of more than 5 to 1, the
difference between the probabilities may be regarded
as significant.

Route, forecasting, and dispatching.- The combined
effects on airplane life of route and of forecasting
and dispatching practices, as contrasted with the
separate effect of operating speed, may be determined
by eliminating, so far as possible, the influences on
the data of differences in operating speed. This
determination may be made by selecting a representative
airspeed for each airline and reducing the data to a
common basis in terms of these representative speeds.
The speed selected for each airline is the "probable
speed" V_p (reference 1), which is the speed that corre-
sponds to the maximum acceleration increment on the
calculated envelopes of figures 5 to 8. The probable
speed is the speed at which the maximum acceleration
increments will most probably be experienced.

The influences of route and of dispatching and
forecasting practices are expressed in terms of the
average number of flight hours required to exceed the
acceleration that would be experienced as the result
of encountering a gust of given effective velocity
at probable speed. The effective gust velocity chosen
for this purpose is 37.5K feet per second, where K is
the gust alleviation factor (reference 7). This
particular value of gust velocity was selected so that
the time required to exceed the resulting accelerations
would be roughly comparable to the time required to
exceed the limit load factor. The average time
required to exceed the acceleration increment produced
by a gust velocity of 37.5K feet per second at probable
speed for each of airlines A, B, and C, as determined
from figure 2, is shown in figure 3. Since the time
scale on this figure is logarithmic, the 5-to-1
criterion for significant differences may be represented
by a constant length and is included in the figure for
purposes of comparison. It will be noted that the
differences among the airlines for prewar operations
are not significant on the basis of the 5-to-1 criterion.
Thus, at least for transcontinental operation in the
United States, differences in route roughness appear
to be so compensated for by variations in the forecasting
and dispatching practices of the airlines that route,
as a significant parameter of airplane life, may be
neglected.

     Forecasting and dispatching over a given route.-
The fact that data from airline A are available for both
prewar and war periods affords an opportunity to determine
the effect on airplane life of changes in forecasting
and dispatching techniques over a given route. During
the war period, either because less adequate facilities
for forecasting were available or because dispatching
techniques were deliberately relaxed, the airplanes were
flown through turbulent air that would have caused
flight cancelation in the prewar period. A direct
evaluation of the effect of these changes may be made
from the times required to exceed an effective gust
velocity of 37.5K feet per second at probable speed
(fig.3). In fact, figure 3 indicates that the average
time required for airline A to exceed this value was
decreased by a factor of 10 during the war period.
Since the probable speed for airline A is the same

for both periods, so that a general similarity of
over-all operating speeds for the two periods may be
inferred, the indicated decrease in time may be attri-
buted directly to the greater turbulence experienced
during the war period as a result of either less adequate
forecasting facilities or relaxed dispatching practices.
Thus, forecasting and dispatching practices over a given
route are of appreciable importance in determining air-
plane life.

Operating speed.- Since the parameters of route,
forecasting, and dispatching have been shown to have had
no significant influence on airplane life during the
prewar period, whatever differences exist among the
operational lives for the three airlines must be attri-
buted to other factors. The operational lives may be
determined directly from figure 3 in terms of the
average flight time required for each airline to exceed
the limit load factor. Although the values given for
airlines A and B are in essential agreement, the
operational life for airline C is significantly higher
than the others. In fact, airline C exceeds the limit
load factor only about one-tenth as often as do airlines
A and B. The values of probable speed in figure 3 show
that the difference is due to the fact that the airplanes
of airline C are flown at low speeds in regions of
turbulence. Whereas airlines A and B have probable
speeds of 175 miles per hour and 170 miles per hour,
respectively, with resulting operational lives of about
equal magnitude, the probable speed of airline C is only
145 miles per hour. Thus operating speed in turbulent air
is apparently of primary importance in the determination
of the operational life of airplanes.

Excessive speed.- The results shown in figure 4,
in which the time required to exceed the limit load
factor in figure 2 and the time required to exceed
placard speed in figure 1 are summarized, indicate a
direct relationship between these factors. Such a
relationship might be expected if, as can be reasonably
assumed, transport airplanes are never intentionally
flown at excessively high speeds and these speeds are
attained only as a result of the loss of control in
turbulent air.

CONCLUSIONS

An analysis was made of the V-G records obtained
from Douglas DC-3 airplanes during commercial transport
operation over three transcontinental routes in the
United States to determine the effects of route,
forecasting and dispatching practices, and operating
speed on the applied loads experienced during commercial
transport operation. The analysis indicated the
following conclusions:

1. For transcontinental operation in the United
States, differences in route roughness are so compensated
for by variations in the forecasting and dispatching
practices of the airlines that route, as a significant
parameter in airplane life, may be neglected.

2. Forecasting and dispatching practices over a
given route, as reflected in differences between prewar
and war operation, are of appreciable importance in
determining airplane life.

3. Operating speed in regions of turbulence is
of primary importance in the determination of the
operational life of airplanes.

4. The average time required to exceed the placard
speed seems to be directly related to the average time
required to exceed the limit load factor.

Langley Memorial Aeronautical Laboratory
    National Advisory Committee for Aeronautics
        Langley Field, Va., April 16, 1946

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TABLE I

CHARACTERISTICS OF DOUGLAS DC-3 AIRPLANES

Gross weight, lb 25,200

Wing area, sq ft 987

Wing span, ft 95

Mean aerodynamic chord, ft 11.5

Slope of lift curve, per radian 4.79

Aspect ratio 9.1

Maximum level-flight speed, mph 211

Placard speed, mph 257

Limit load factor, g 3.14

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TABLE II

SUMMARY OF V-G RECORDS SUPPLIED FOR ANALYSIS

Operator	Records supplied		Ranges of flight hours used in analysis	Records used in analysis		
	Number of records	Total flight hours		Number of records	Total flight hours	Average flight hours per record, τ
A (prewar)	35	17,675	575 to 600	15	9,691	645
A (war)	33	20,002	600 to 800	20	13,911	695
B (prewar)	52	12,048	200 to 400	37	10,187	275
C (prewar)	13	4,485	150 to 450	11	3,232	295

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TABLE III

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF V_{max}

Velocity (mph)	Frequency for airline A, prewar	Frequency for airline A, war	Frequency for airline B, prewar	Frequency for airline C, prewar
190 to 194				1
195 to 199				1
200 to 204			4	3
205 to 209		1	7	3
210 to 214		3	6	2
215 to 219	1	1	13	
220 to 224	4	4	3	
225 to 229	3	2	1	1
230 to 234	4	5	1	
235 to 239	2	2	1	
240 to 244				
245 to 249		1		
250 to 254	1			
255 to 259			1	
260 to 264		1		
Total	15	20	37	11
$\overline{V}_{max}$	229.8	227.8	215.7	206.6
σ	8.3	12.7	9.9	8.7
α	1.04	0.77	1.48	0.79

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TABLE IV

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF Δn_{max}

Acceleration increment (g units)	Frequency for airline A, prewar	Frequency for airline A, war	Frequency for airline B, prewar	Frequency for airline C, prewar
0.30 to 0.39				1
0.40 to 0.49				2
0.50 to 0.59			1	2
0.60 to 0.69	1		3	1
0.70 to 0.79	1	2	1	3
0.80 to 0.89	2		9	3
0.90 to 0.99	2	2	6	2
1.00 to 1.09	4	5	8	3
1.10 to 1.19	4	2	14	2
1.20 to 1.29	6	5	9	
1.30 to 1.39	4	4	6	
1.40 to 1.49	2	5	5	3
1.50 to 1.59		1	3	
1.60 to 1.69		4	2	
1.70 to 1.79	3	1	2	
1.80 to 1.89		3	2	
1.90 to 1.99	1	3		
2.00 to 2.09		1	1	
2.10 to 2.19			2	
2.20 to 2.29				
2.30 to 2.39		1		
2.40 to 2.49		1		
Total	30	40	74	22
$\overline{\Delta n_{max}}$	1.23	1.45	1.21	0.89
σ	0.30	0.39	0.34	0.32
α	0.46	0.48	0.74	0.25

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TABLE V

FREQUENCY DISTRIBUTIONS AND STATISTICAL PARAMETERS OF V_o

Velocity (mph)	Frequency for airline A, prewar	Frequency for airline A, war	Frequency for airline B, prewar	Frequency for airline C, prewar
100 to 109		3	1	
110 to 119	1	3	4	
120 to 129			6	3
130 to 139	1	2	8	2
140 to 149	3	1	5	8
150 to 159	3	3	13	4
160 to 169	4	5	9	3
170 to 179	6	6	13	1
180 to 189	7	6	8	
190 to 199	2	4	5	1
200 to 209	3	7	2	
Total	30	40	74	22
$\overline{V}_o$	172.0	168.5	158.9	149.5
σ	21.2	30.9	24.2	16.4
α	-0.57	-0.75	-0.22	0.73

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Fig. 1   NACA TN No. 1142
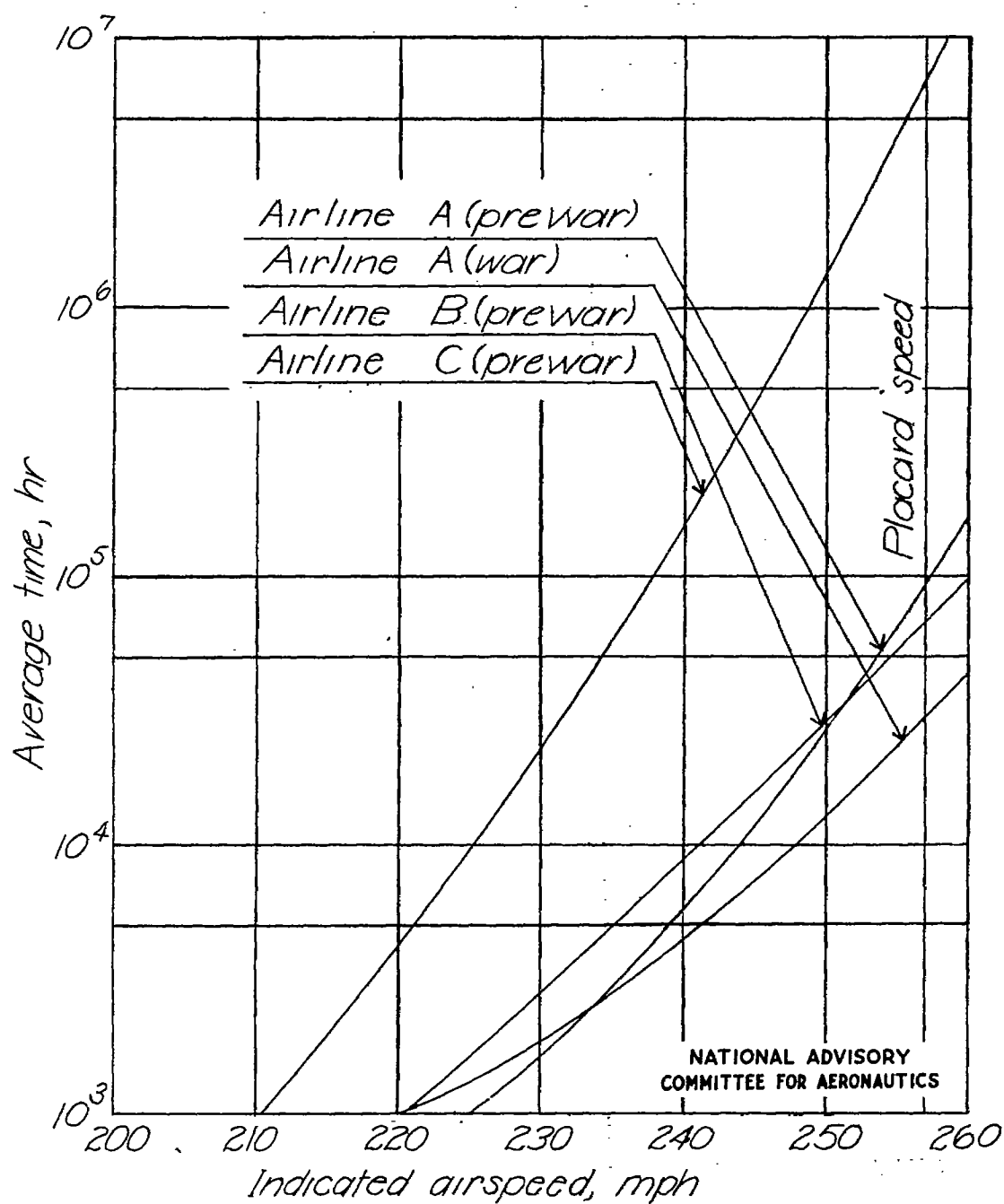
Figure 1.—Average time required to exceed a given value of airspeed.
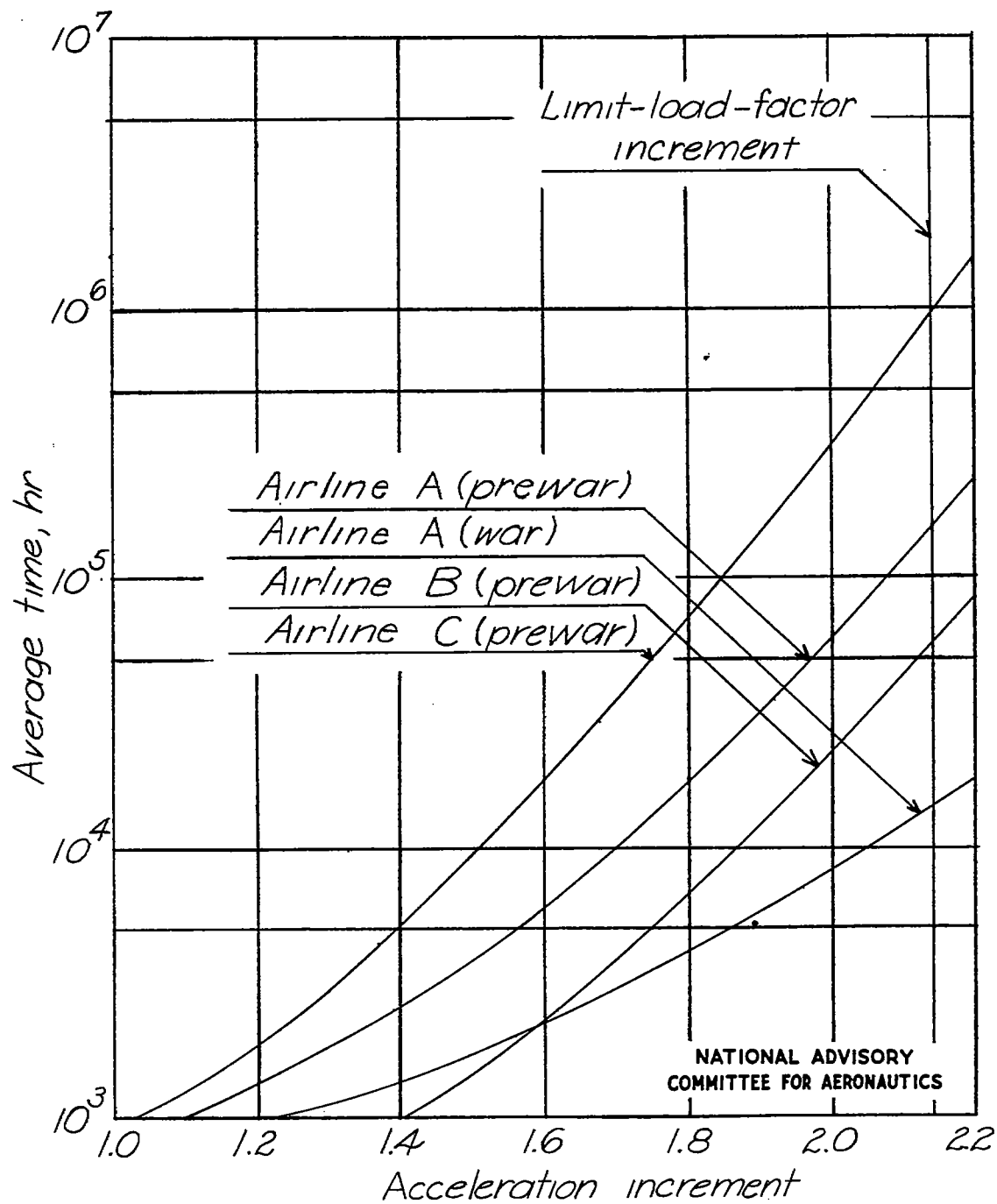
Figure 2.— Average time required to exceed a given acceleration increment.

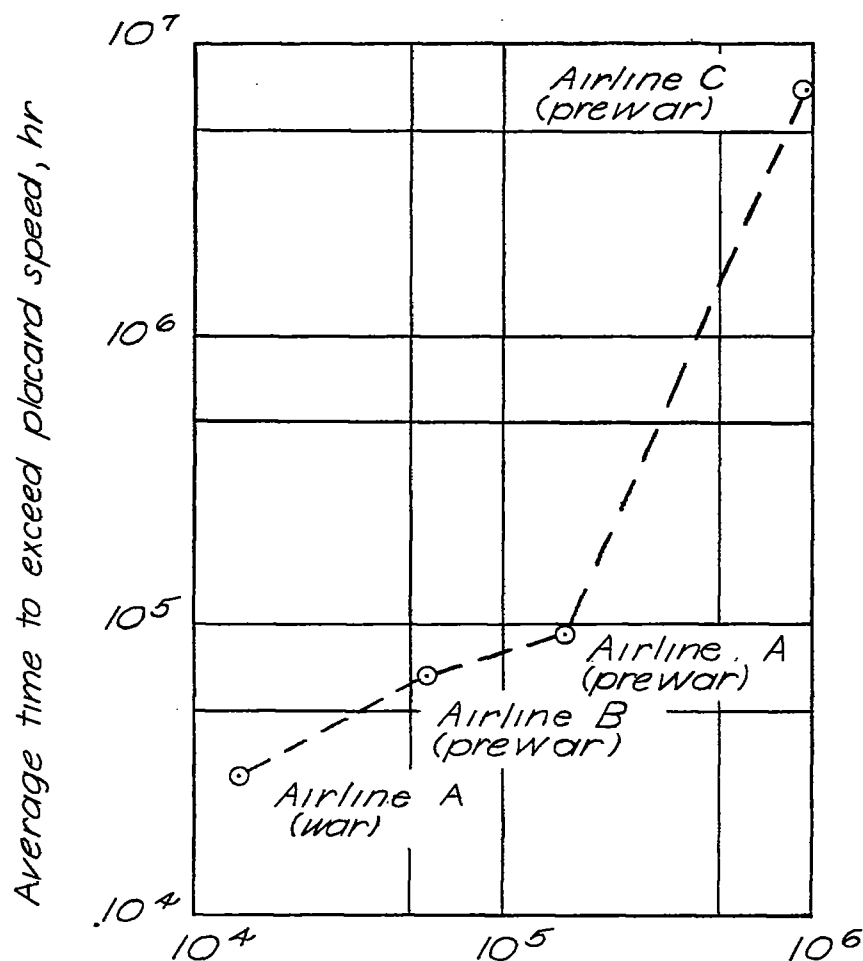Fig. 3
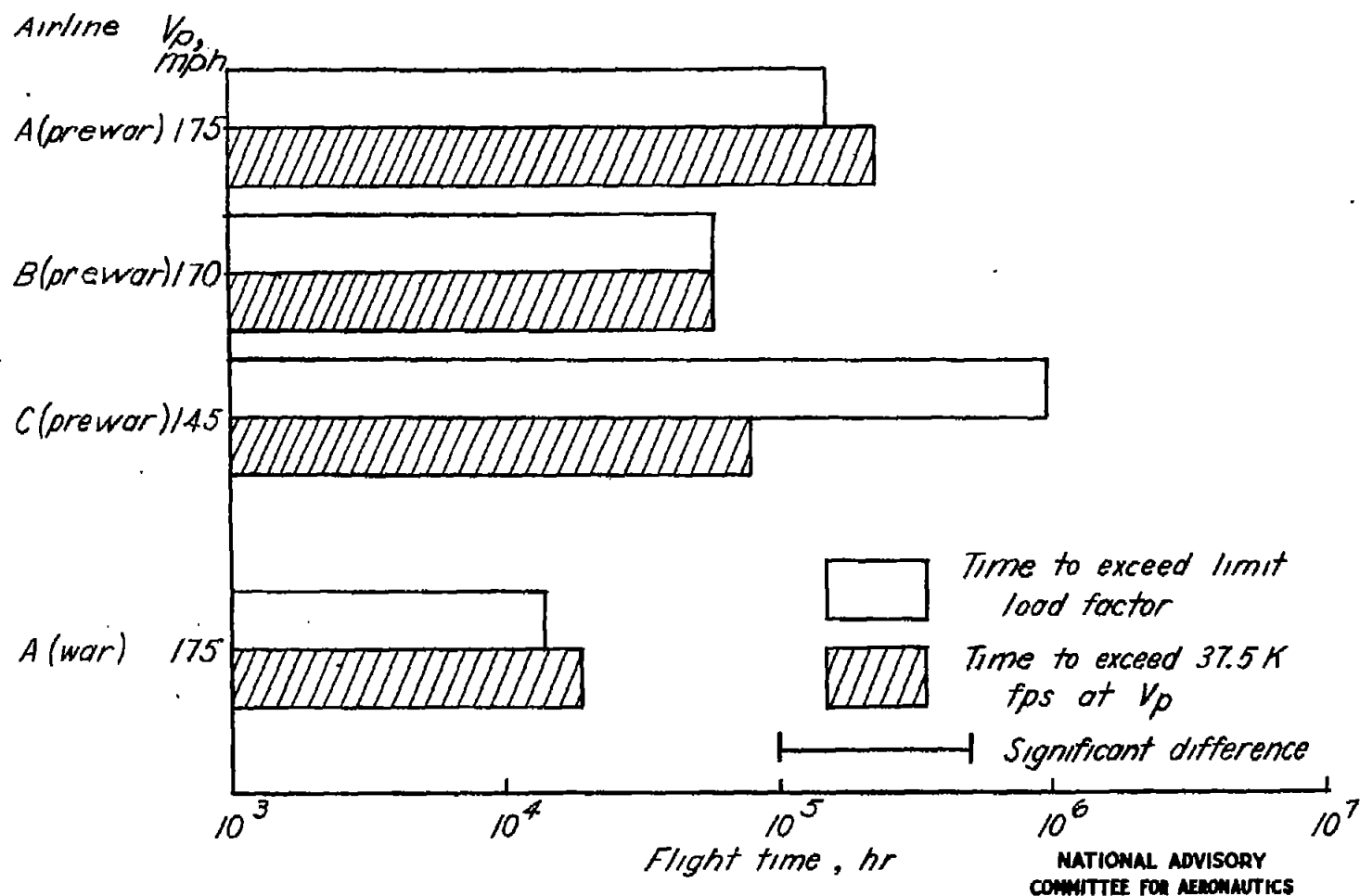
Figure 3.—Average time required to exceed limit load factor and to exceed fixed effective gust velocity at probable speed.

Figure 4.—Relation between average time required to
   exceed limit-load-factor increment and average
   time required to exceed placard speed.

Fig. 5
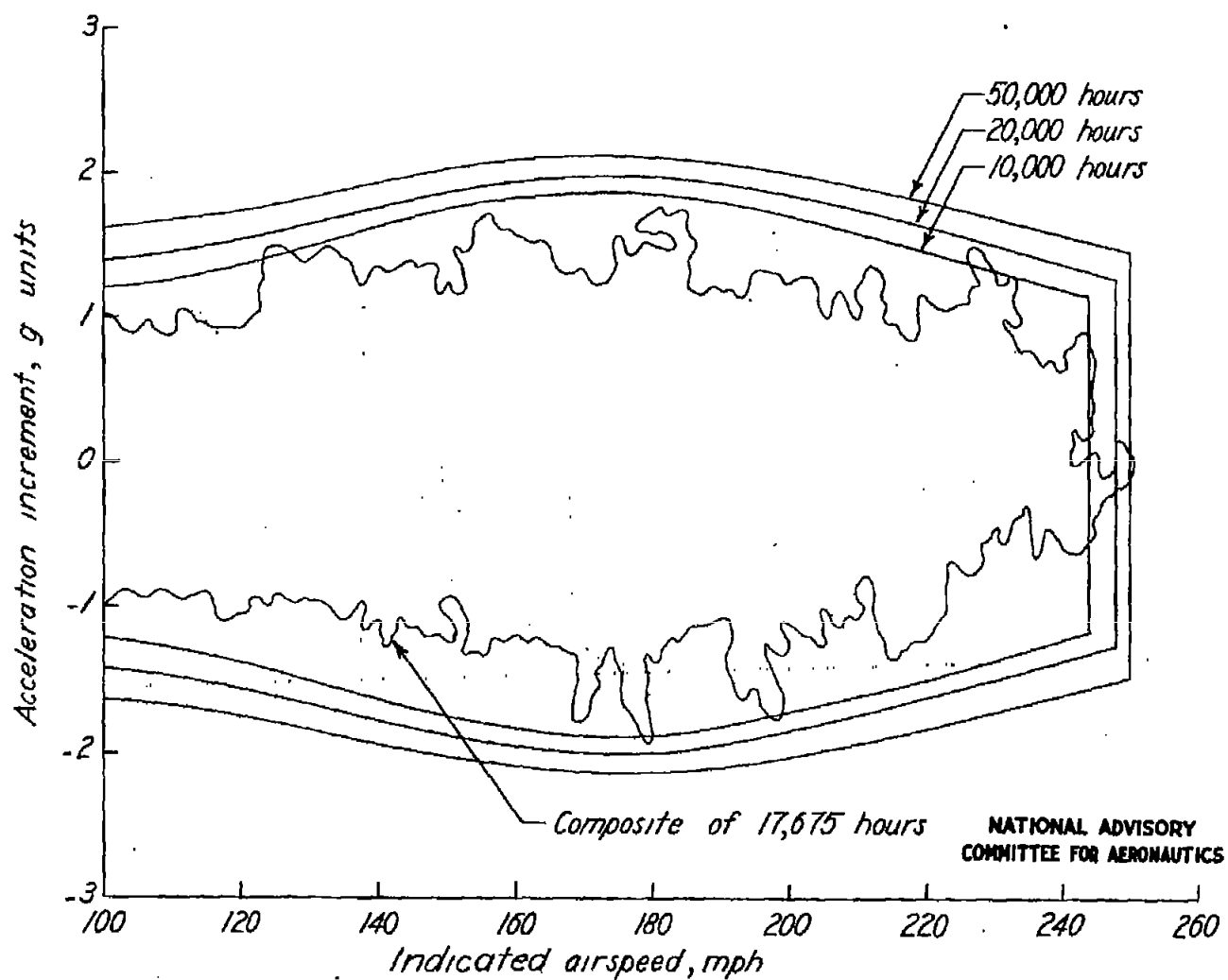
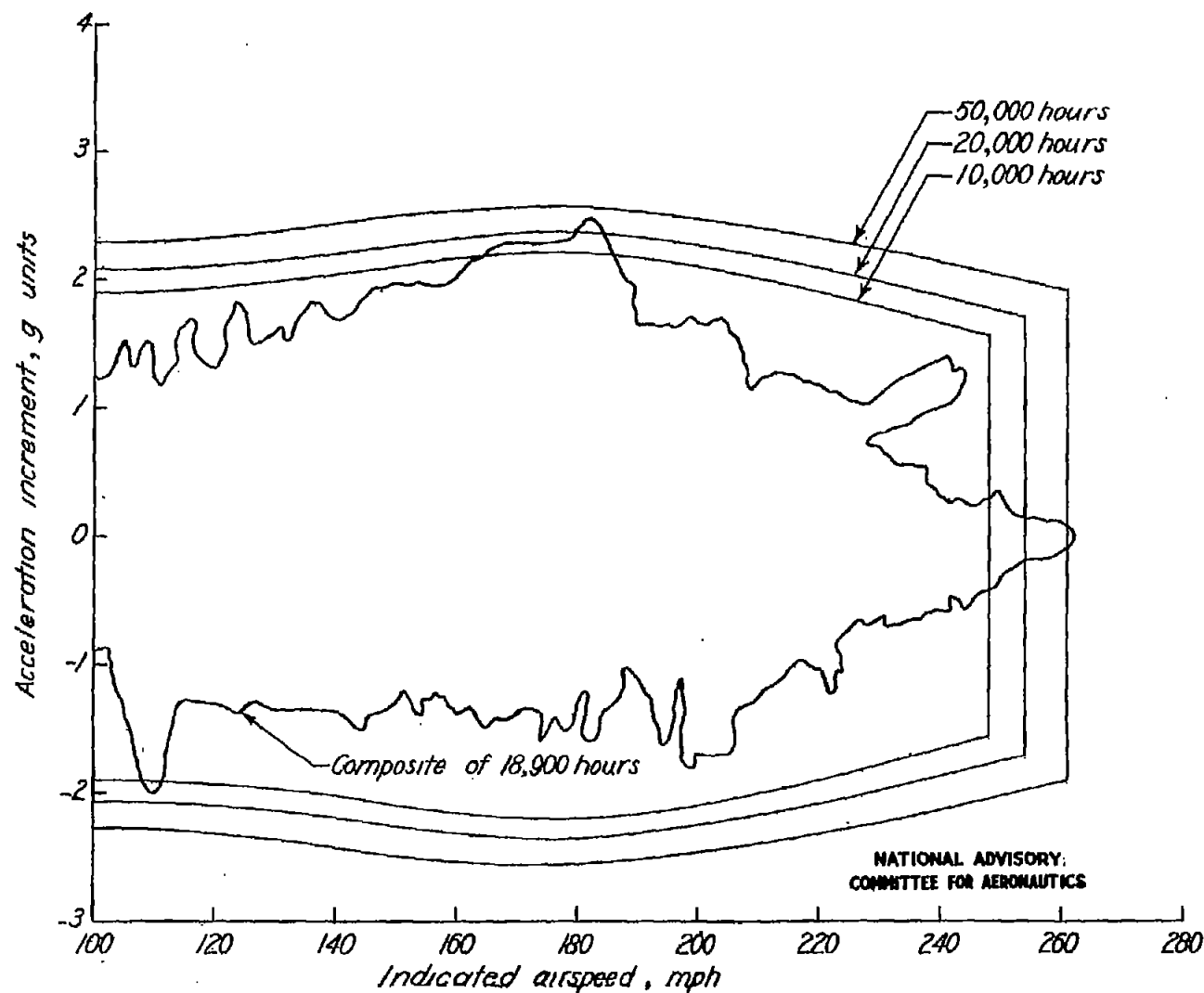Figure 5.—Comparison of calculated flight envelopes with composite of V-G envelopes obtained by airline A during prewar operation.

Figure 6.— Comparison of calculated flight envelopes with composite of V-G envelopes obtained by airline A during war operation.
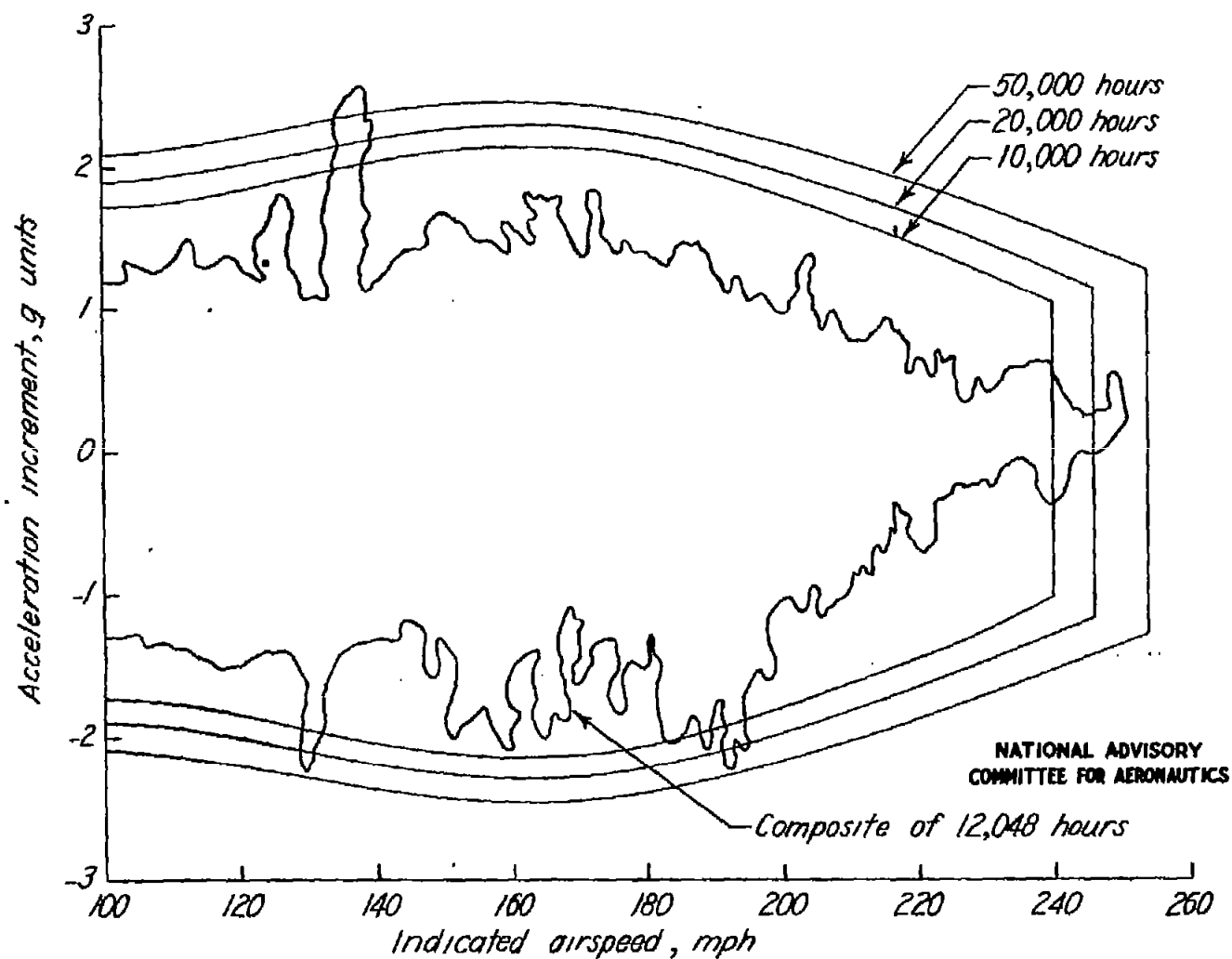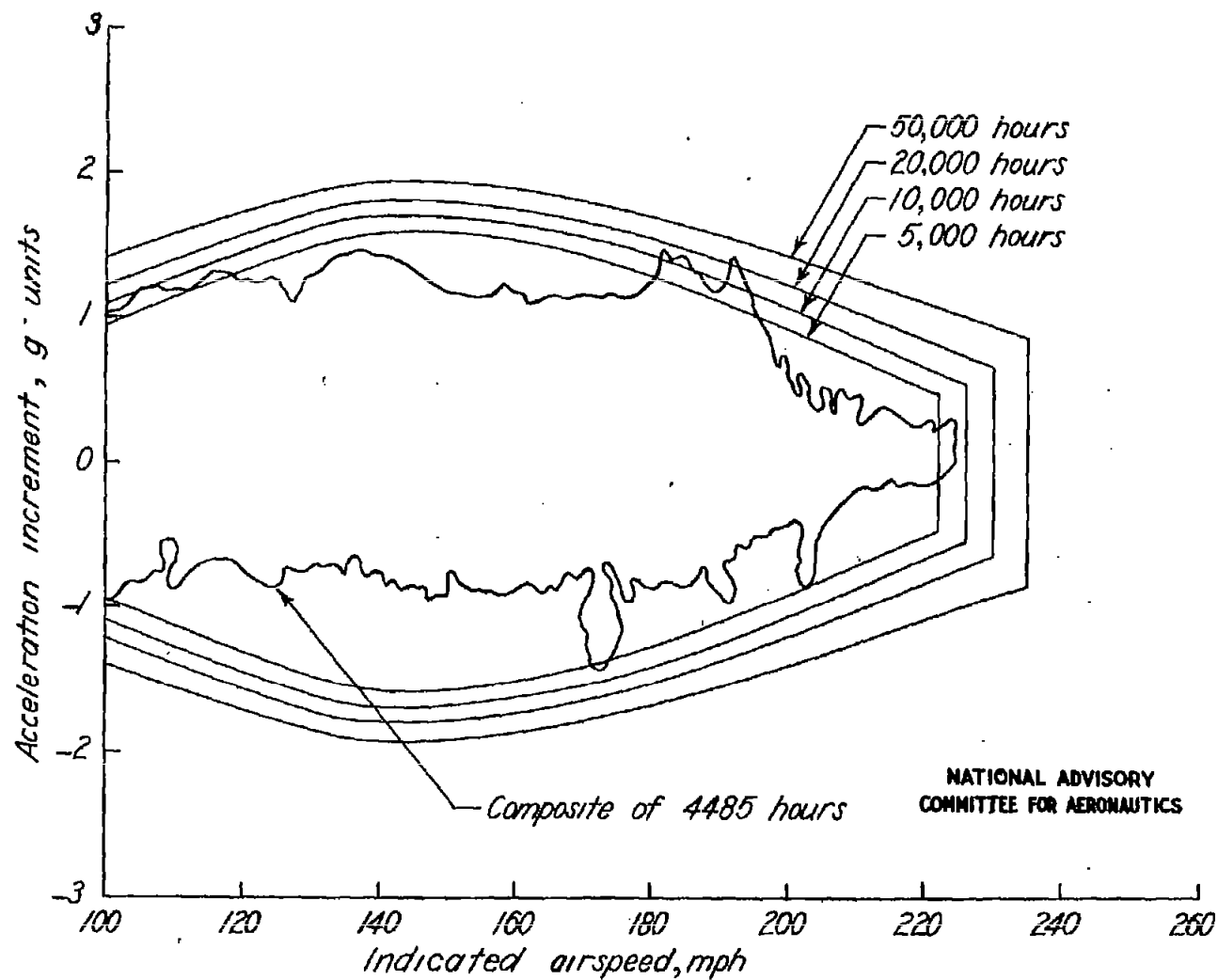
Fig. 6

Fig. 7

Figure 7.—Comparison of calculated flight envelopes with composite of V-G envelopes obtained by airline B during prewar operation.

Figure 8. — Comparison of calculated flight envelopes with composite of V-G envelopes obtained by airline C during prewar operation.
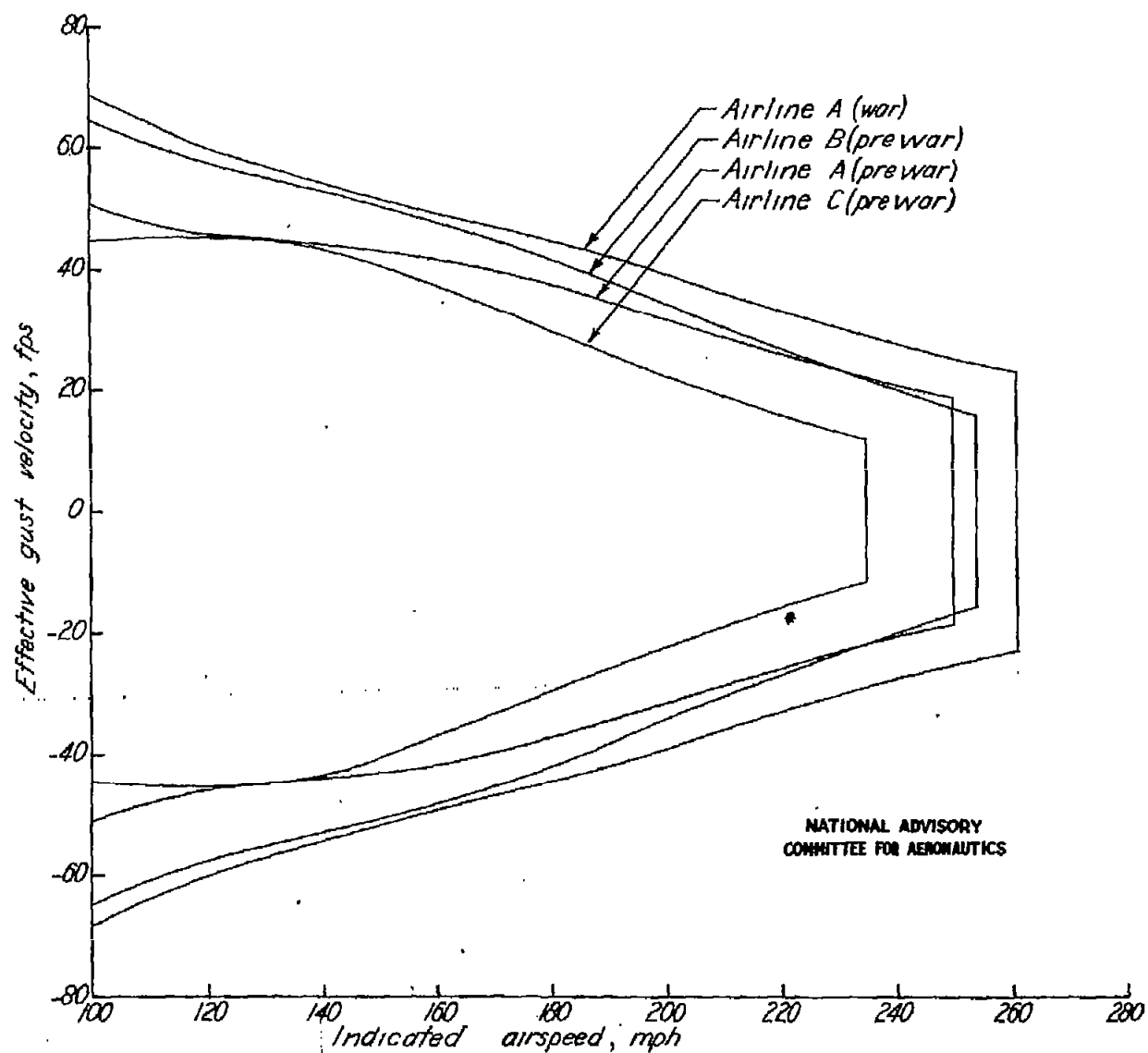
Fig. 8

Fig. 9

Figure 9.-Effective-gust-velocity envelopes for 50,000 hours of operation.